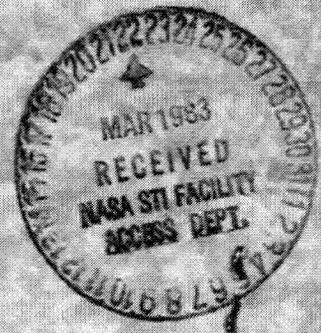# Corrosion of Simulated Bearing Components of Three Bearing Steels in the Presence of Chloride-Contaminated Lubricant

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CORROSION OF SIMULATED BEARING COMPONENTS OF THREE BEARING STEELS

IN THE PRESENCE OF CHLORIDE-CONTAMINATED LUBRICANT

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ABSTRACT

Corrosion tests were run with AISI 52100, AISI M-50 and AMS 5749 under conditions that simulate the crevice corrosion found in aircraft ball and roller bearings rejected at overhaul for corrosion. Test specimens were fabricated that simulated the contacts of balls or rollers and the raceways. Corrosion cells were assembled in the presence of a lubricant contaminated with water and chloride ions. The cell was then thermally cycled between 339 K (150° F) and 276 K (37° F). The corrosion observed after 14 cycles was that of crevice and pitting corrosion typically found in aircraft bearings. AMS 5749 showed a very slight amount of corrosion. No appreciable differences were noted between AISI 52100 and AISI M-50, but both showed much greater corrosion than AMS 5749. The corrosion pits observed in AISI M-50 appeared to be fewer in number but generally deeper and larger than in AISI 52100.

INTRODUCTION

Corrosion of aerospace bearings has become a serious and expensive problem. The corrosion problem is most severe in systems with long periods of nonuse. A summary of causes for bearing rejection at a U.S. Navy facility (1) shows that corrosion accounts for nearly one-third of the bearing rejections from their aircraft systems, including drivelines, wheels, and accessories. Air Force experience (2) confirms that corrosion is a major cause of rejection at overhaul of aircraft turbine engine bearings.

Cryogenic turbopump bearings in current and future rocket engines, such as the Space Shuttle Main Engine, also require the use of corrosion resistant bearings. Currently, AISI 440C is used for bearings in cryogenic applications. Its hardness, fatigue life, and load capacity make AISI 440C a marginal material for future cryogenic turbopump bearings and inadequate for turbine-engine main-shaft bearings. A significant mechanism of corrosion in aircraft engine bearings was defined in (3 and 4) as a result of observations from Naval fleet aircraft bearings. It was concluded that the corrosion responsible for bearing rejections was caused by cyclic temperatures and lengthy static periods frequently experienced by aircraft in the field. Temperature of the lubricant in these engines cycles from 508 K (455° F) during operation to 273 K (32° F) during inactive periods in cold climates.

Moisture-laden air can get into the lubrication system in humid environments, during rain, or during aircraft water wash. The moisture can condense on bearing components during the inactive periods. Additionally, it was found (3 and 4) that up to 3 ppm of chloride ion (most likely from sea water) was contained in the lubricant. Observations of rejected bearings showed that the corrosion was concentrated at the crevice formed at the contacts of the balls or rollers and the raceways. The lubricant and condensate containing the chloride ion settled in this area, and crevice corrosion occurred. The presence of the chloride ions accelerates corrosion (5).

Although the observations in (3 and 4) were limited to bearings in Naval aircraft, it is likely that a similar mechanism occurs in other aircraft and aerospace bearings rejected for corrosion. If the corrosion pits are of significant size, they can act as initiation sites for fatigue spalling and shorten bearing life.

The corrosion problem is being attacked on three major fronts: corrosion-resistant materials, corrosion-resistant coatings or surface modifications, and corrosion-inhibited lubricants. Materials such as AISI 440C, AMS 5900, and AMS 5749 are called corrosion-resistant or stainless steels, but under some severe environmental conditions in aircraft bearings, corrosion will occur. They are, however, more corrosion-resistant than the common aircraft bearing materials such as AISI M-50, AISI 52100, and the commonly used case-carburized materials. Ceramics such as silicon nitride are truly corrosion-resistant in the aircraft environment. Although this material is not yet well developed for widespread aircraft application, it could be applied in some specific cases.

Chromium-ion implantation has shown significant improvement in the corrosion resistance of AISI M-50 (6). Other surface modifications or coatings may also provide similar benefits but more work is needed in this area. It is probable that a combination of approaches, such as the use of silicon nitride balls or rollers and coated raceways may be a viable solution for some applications that require long periods of nonuse.

Currently, the lubricant provides some measure of corrosion protection in aircraft bearings simply by keeping the components coated and moisture free. Corrosion inhibiting additives for the commonly used MIL-L-23699 lubricant have shown promise in laboratory tests (3 and 4) and confirmation of the degree of improved corrosion resistance in actual aircraft systems is under way.

Steels such as AMS 5749 and AMS 5900 combine the tempering, hot hardness, and hardness-retention characteristics of AISI M-50 steel with the corrosion and oxidation resistance of AISI 440C stainless steel. The typical chemical compositions of these materials are shown in Table 1. AMS 5749 and AMS 5900 contain higher percentages of carbon and chromium than AISI M-50 for improved corrosion and wear resistance. Their hot hardness and hardness retention are better than AISI 440C and similar to AISI M-50 (7).

AMS 5749 and AMS 5900 have shown excellent life in several accelerated rolling-element fatigue studies (7 to 10). These materials were double-vacuum-melted (VIM-VAR for vacuum induction melt, vacuum arc remelt) and showed lines equal to or greater than VIM-VAR AISI M-50 in similar tests. These life results are significant, since they show that a corrosion-resistant material that could potentially replace AISI M-50 in some aircraft bearing applications would be expected to have at least equivalent lives.

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The extent of corrosion resistance improvement of these materials over the more common aircraft bearing materials such as AISI M-50 and AISI 52100 has not been well documented or published. It was the objective of the work reported herein to determine the corrosion resistance of AMS 5749 relative to that of AISI M-50 and AISI 52100.

The objective was accomplished by performing a series of corrosion tests with specimens fabricated to simulate the crevice corrosion in the presence of a specially prepared lubricant-chloride solution and exposed to thermal cycling.

TEST MATERIALS

The chemical composition of the materials used in these tests is given in Table 1. The test specimens were made from rolling-contact (RC) rig test bars (11). Rod materials of approximately 13 mm (0.5 in) in diameter were heat treated to obtain a nominal Rockwell C hardness of 62. The heat treating cycles are described in Table 2. Cylindrical bars 76.2 mm (3.0 in) long and 9.5 mm (0.375 in) in diameter were ground from the heat treated rods. Half of the test bars were ground with saddles as shown in Fig. 1 with a radius slightly greater than the bar radius. This saddle provides a contact and crevice situation to simulate the contact of a ball or roller and a bearing raceway as shown in Fig. 1. Both the cylindrical and the saddle surfaces were ground to a finish of 0.15 to 0.20 µm (6 to 8 µin).

The lubricant used on the bars during the corrosion tests was a specially prepared lubricant-chloride solution. It consisted of MIL-L-23699 type lubricant to which was added three parts per million (ppm) by weight of chlorides (supplied as ASTM D665 synthetic seawater). The water content of the lubricant solution was then adjusted to 600 ppm by weight by the addition of distilled water.

CORROSION TEST PROCEDURE

The procedure used for these corrosion tests was similar to that used in (3). The test bars of each material were cleaned by successively washing in separate baths of toluene, ethanol, hexane, and acetone. Thereafter, the bars were handled only by rubber-gloved hands and were air-dried at room temperature. The bars were then immersed for 1 hour in the lubricant-chloride solution. During this exposure, they were periodically rotated. The bars were removed and drained for 30 minutes at room temperature.

The bars were then placed in a special fixture, shown in Fig. 2, with the lower two bars having the saddle, and the mating two bars placed across the saddles. This arrangement produces a contact and crevice situation similar to that in a ball or roller bearing and provides the opportunity for the crevice corrosion mechanism. The fixture was made of polyethylene material. The fixture was clamped together and suspended in a large beaker which was then loosely covered with aluminum foil. This assembly, called the corrosion cell, was then cycled alternately between a 339 K (150° F) oven and a 276 K (37° F) refrigerator. Total exposure was 14 cycles, each cycle consisting of 8 hours in the oven and 16 hours in the refrigerator. Corrosion cells were assembled with each of the three materials.

Upon completion of the exposure, the bars were removed, cleaned with an alkaline solution in an ultrasonic cleaner, and photographed. Typical corro-

sion sites were then examined metallographically to determine corrosion characteristics.

RESULTS AND DISCUSSION

Corrosion tests were performed with test bars of AMS 5749, AISI 52100, and AISI M-50 assembled to simulate crevice corrosion in the presence of a lubricant-chloride solution. After the 14 thermal cycles were completed, the test bars were cleaned and examined. Visual inspection revealed that AISI M-50 and AISI 52100 had extensive corrosion damage. A slight amount of corrosion was present on the AMS 5749 bars. As shown in Figs. 3 and 4, the corrosion was not limited to crevice corrosion, but pitting corrosion also occurred on exposed surfaces of both materials. The slight amount of corrosion on the AMS 5749 bars appeared to be limited to the saddle area where crevice corrosion occurred, as shown in Fig. 5.

For a detailed examination of the corrosion damage, scanning electron microscopy was employed. Typical corrosion areas are shown in Figs. 6 to 8. In general, there was no significant difference between the corrosion in the crevice areas and that on the exposed surfaces. Differences were noted between the appearance of the AISI M-50 and the AISI 52100. The corrosion on AISI 52100 appeared to cover more surface area, but the corrosion pits on the AISI M-50 bars appeared to be deeper. This observation is not readily apparent in Figs. 6 and 7, but test bars of both materials were sectioned through typical corrosion pits for further observations.

Optical photomicrographs of the sections through the pits are shown in Figs. 9 and 10. The greater depths of the AISI M-50 corrosion pits are apparent by comparing these photos. This observation agrees with those of (12) which illustrate that effect in bearings removed from service.

The corrosion pitting on the AMS 5749 was very limited in area and only in the crevice area near the edge of the saddle as shown in Figure 8. These few pits are very shallow, as shown in Fig. 11.

The pits shown in Figs. 9 to 11 were selected as typical of the deepest pits observed in each material. These deepest pits had depths of approximately 120, 70, and 20 μm (0.005, 0.003, and 0.0008 in) in the AISI M-50, AISI 52100, and AMS 5749, respectively. The deepest pits in a bearing surface are the most detrimental, since they are most likely to be initiation sites for rolling-element fatigue cracks and subsequent spalling. Thus, the corrosion observed would tend to reduce rolling-element fatigue life in AISI M-50 more than in either AISI 52100 or AMS 5749.

SUMMARY OF RESULTS

Corrosion tests were performed with test bars of AMS 5749, AISI 52100, and AISI M-50 assembled to simulate crevice corrosion in the presence of a lubricant-chloride solution. The assembled corrosion cells were thermally cycled between 339 K (150° F) in an oven for 8 hours and 276 K (37° F) in a refrigerator for 16 hours. Total exposure time was 14 cycles. Following this exposure, the corrosion cells were disassembled, cleaned, observed, and metallurgically examined.

The following results were obtained:
1. The corrosion resistance of AMS 5749 was much better than that of AISI M-50 or 52100.

2. No appreciable differences were noted between the general corrosion resistance of AISI M-50 and AISI 52100, but the pits in AISI M-50 were significantly deeper and larger.

3. The corrosion test fixture and procedure used successfully simulated the crevice corrosion typically found in rejected aircraft bearings.

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TABLE 1. - CHEMICAL COMPOSITIONS OF TEST MATERIALS

	C	Mn	Si	Cr	Mo	V	Ni	S	P
CEVM AISI 52100	1.04	0.34	0.30	1.46	0.03	----	0.04	0.003	0.008
VIM-VAR AISI M50	.82	.28	.24	4.20	4.16	1.01	.08	.002	.007
VIM-VAR AMS 5749	1.11	.17	.30	13.92	3.87	1.15	.01	.003	.003

TABLE 2. - HEAT TREATMENT OF TEST MATERIALS

Heat treatment	Material		
	AISI 52100	AISI M-50	AMS 5749
Preheat	None	816° C (1500° F) in salt	816° C (1500° F) in salt
Austenitize	843° C (1550° F) in salt	1107° C (2025° F) in salt	1121° C (2050° F) in salt
Quench	In 54° C (130° F) oil, air cool to room temperature	In 566° C (1050° F) in salt, air cool to room temperature	In 593° C (1100° F) in salt, air cool to room temperature
Temper	177° C (350° F) for 2 hours	524° C (975° F) for 2 hours	538° C (1000° F) for 2 hours
Deep freeze	-73° C (-100° F) for 2 hours	-73° C (-100° F) for 2 hours	-73° C (-100° F) for 2 hours
Temper	177° C (350° F) for 2 hours	524° C (975° F) for 2 hours	538° C (1000° F) for 2 hours
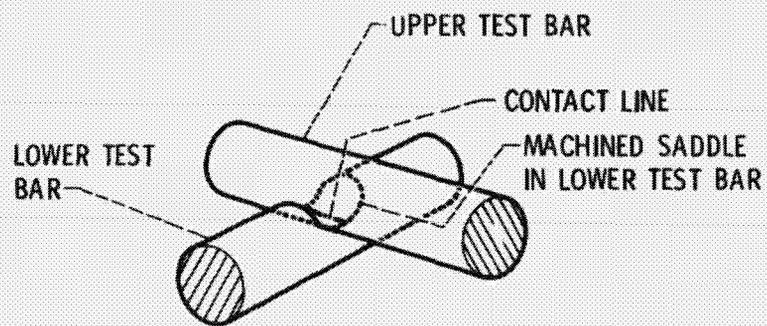
Figure 1. - Corrosion test bar contact.

Figure 2. - Specimens and test fixtures after corrosion test.

Figure 3. - Macrophotos of AISI 52100 specimens after corrosion test.

Figure 4. - Macrophotos of M-50 specimens after corrosion test.
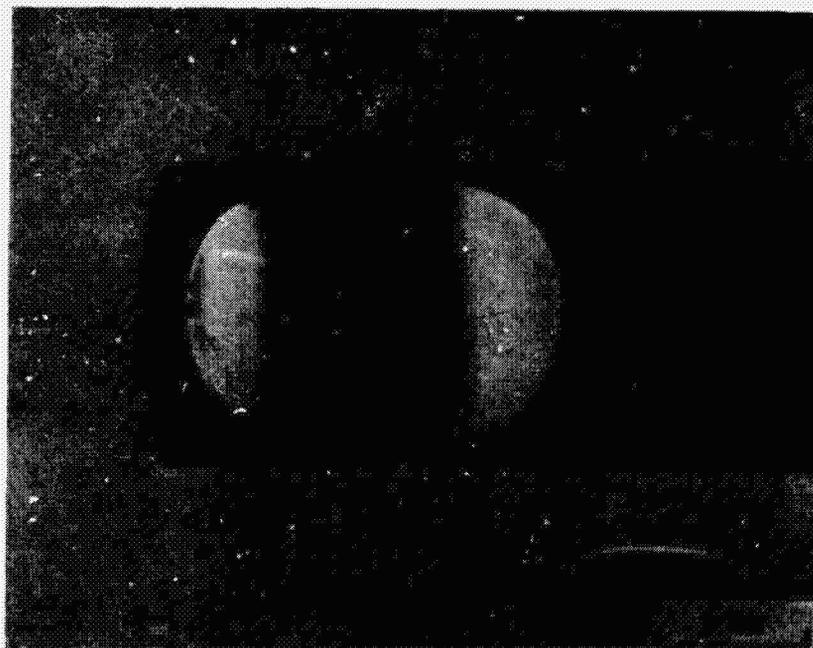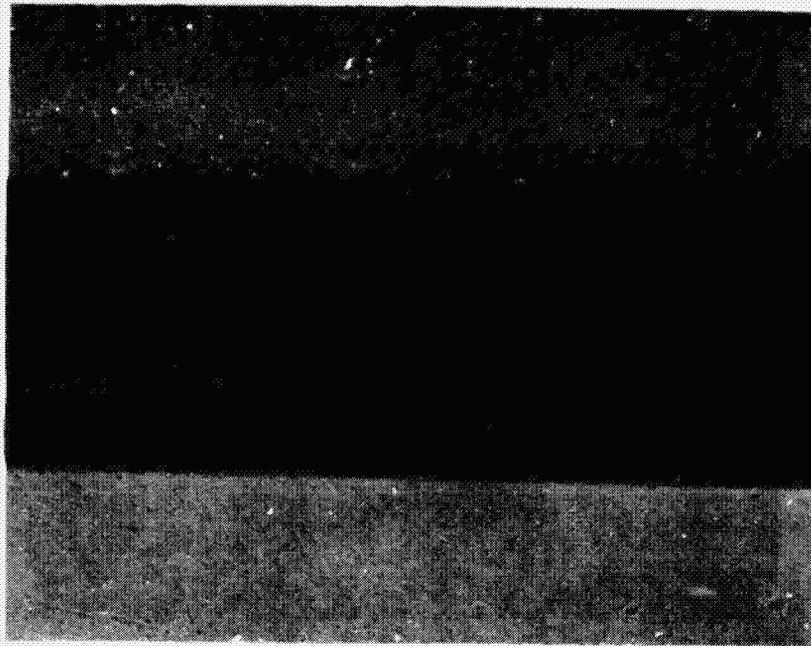
Figure 5. - Macrophotos of AMS 5749 specimens after corrosion test.
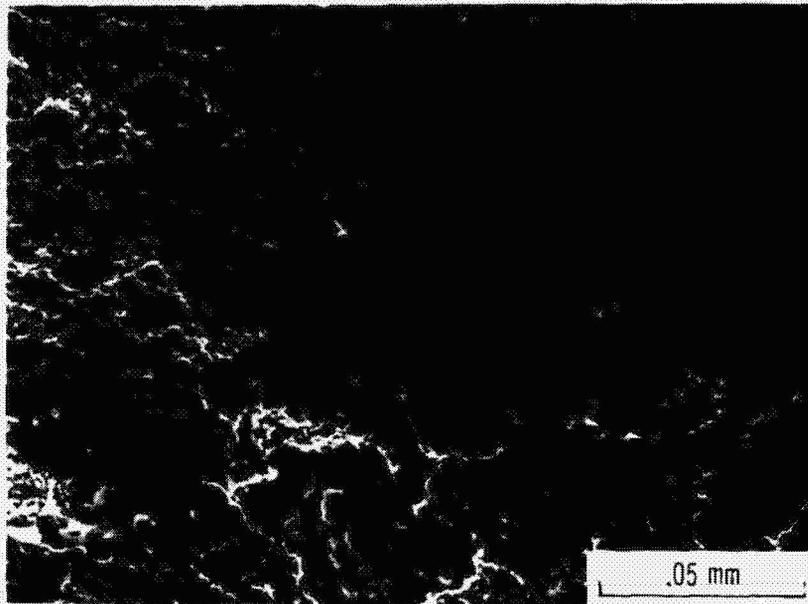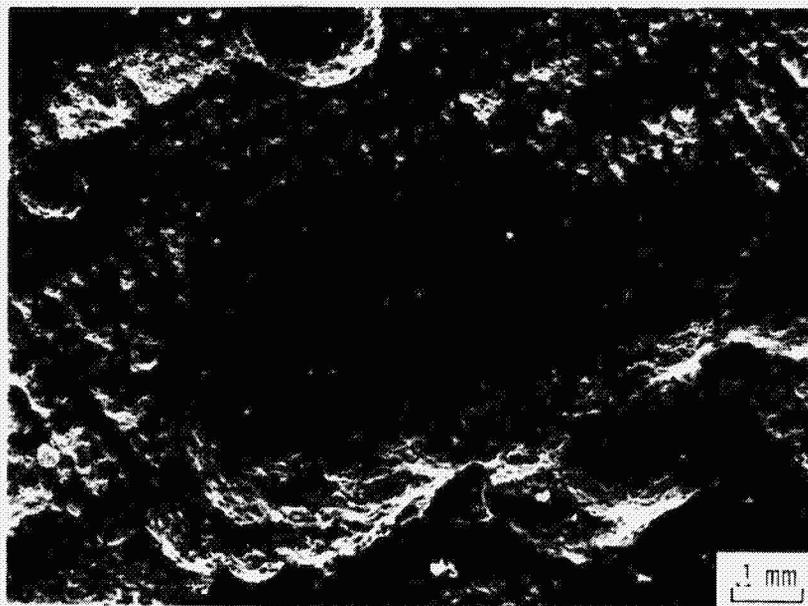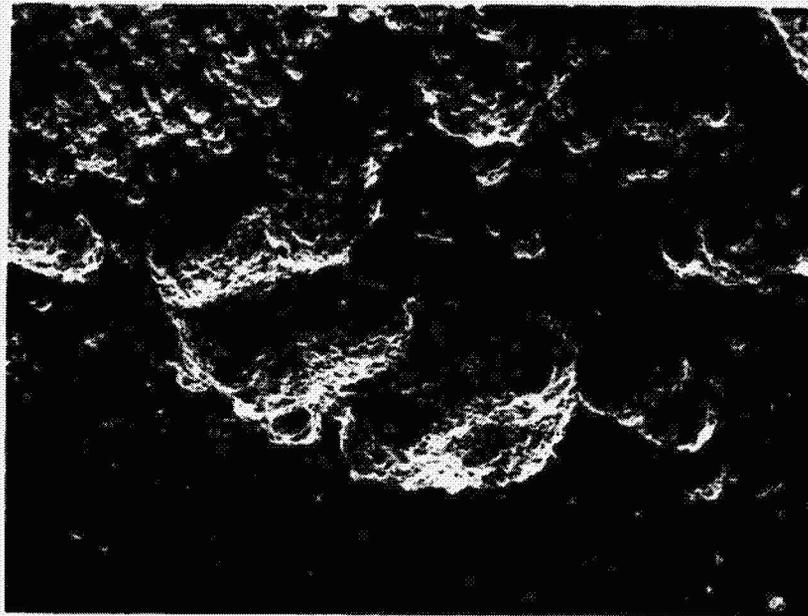
Figure 6. - Concluded.

Figure 7. - Scanning electron micrographs of AISI M-50 specimen after corrosion test.

.1 mm
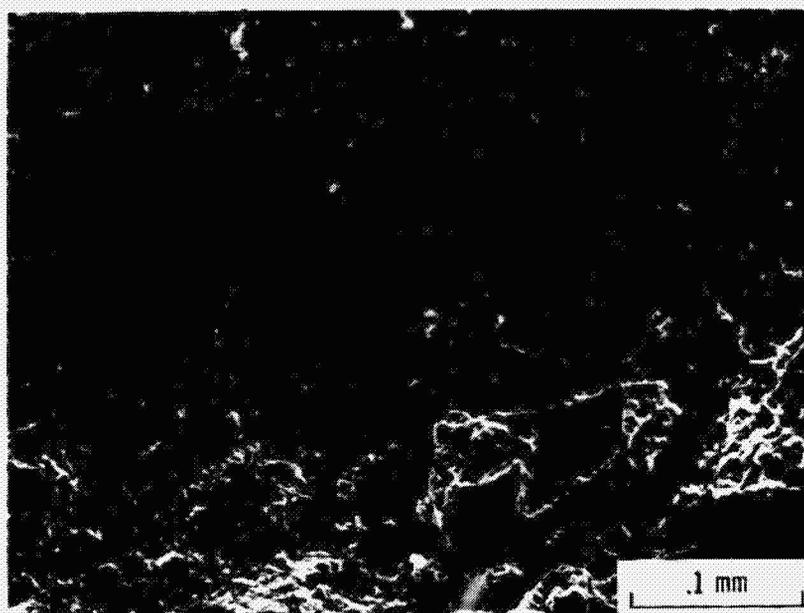
Figure 7. - Concluded.
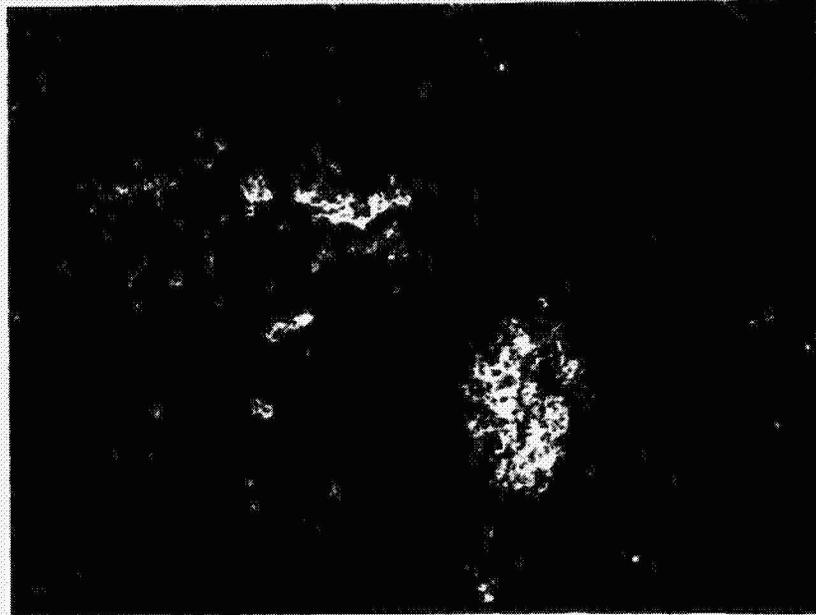
Figure 8. - Scanning electron micrographs of AMS 5749 specimen after corrosion test.

.1 mm
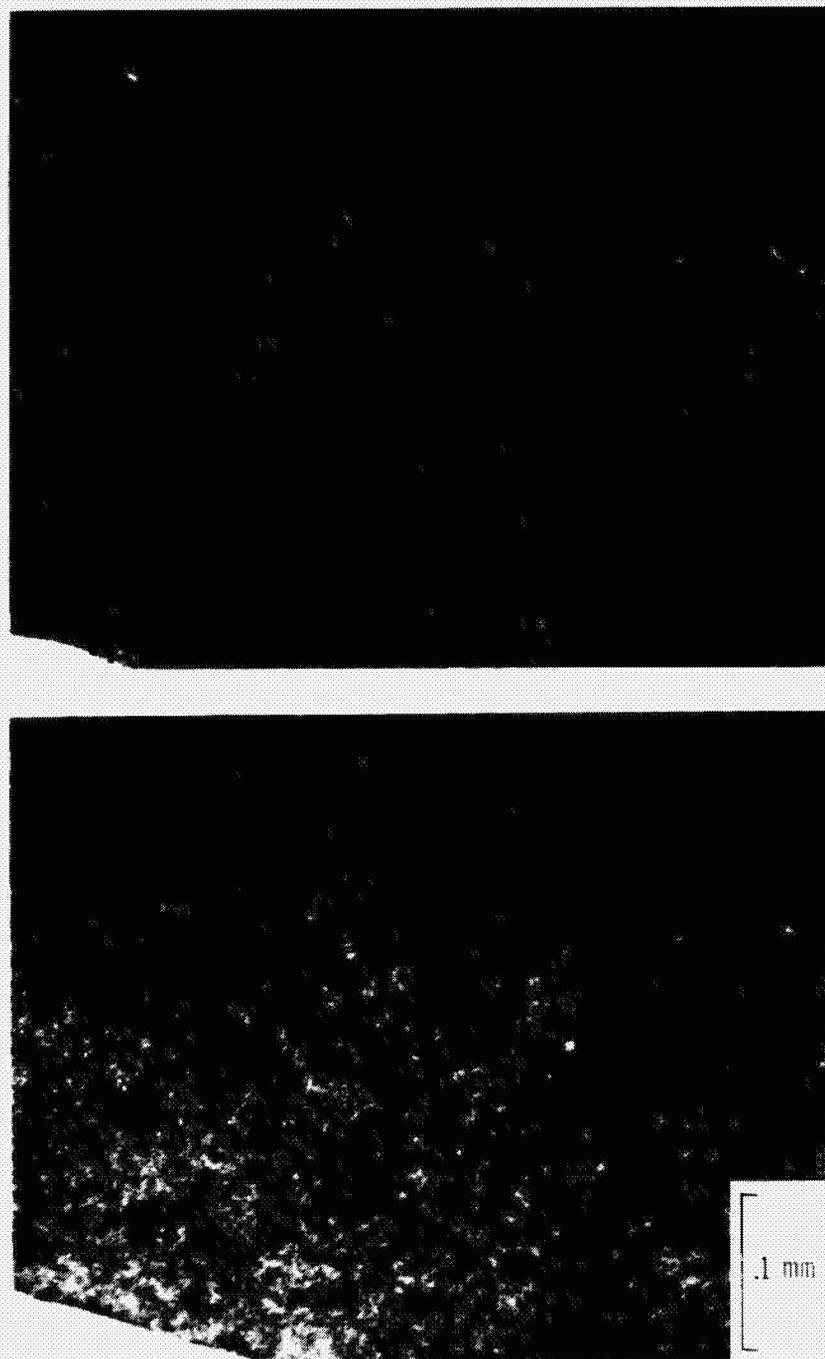
Figure 9. - Optical micrograph of AISI 52100 specimen after
corrosion test.
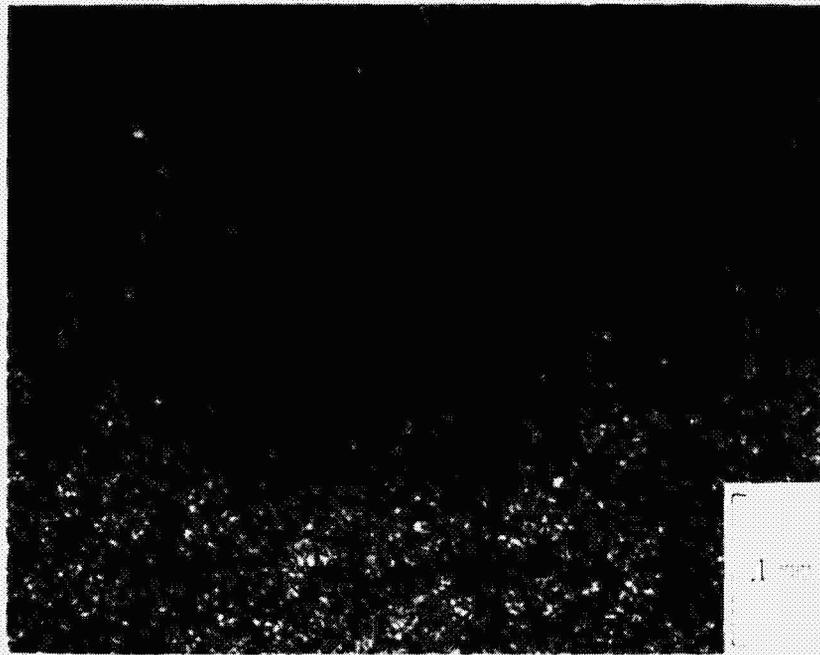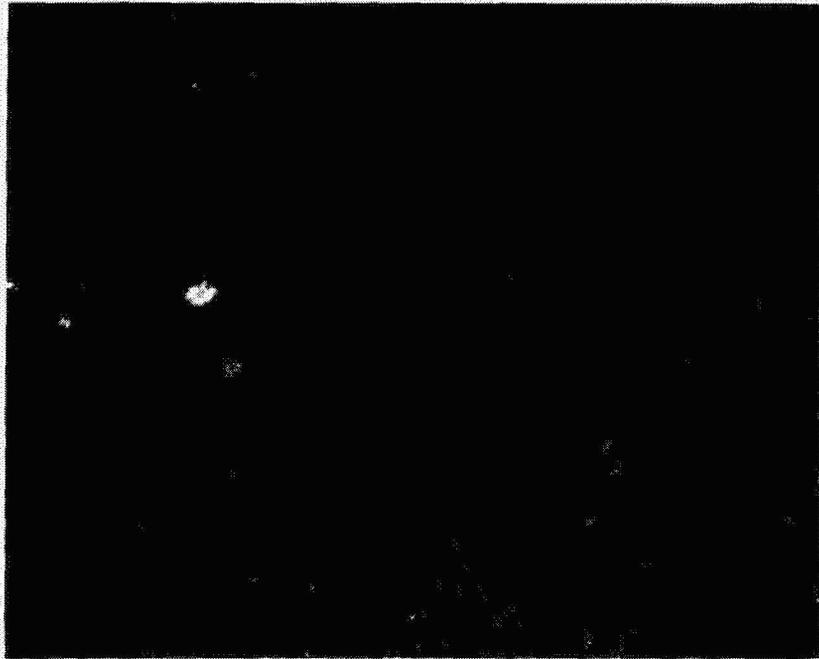
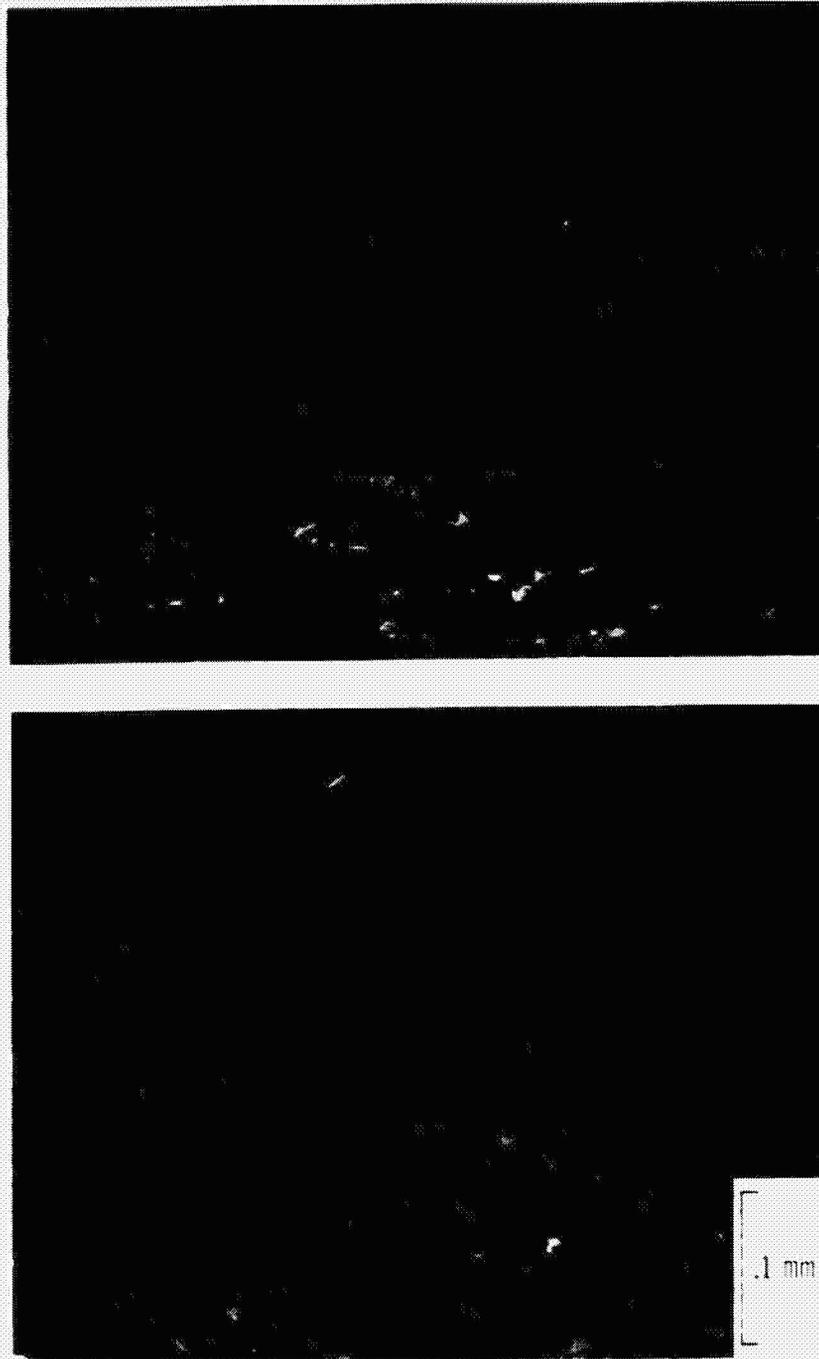Figure 10. - Optical micrograph of AISI 9310 specimen after corrosion test.

.1 mm

Figure 11. - Optical micrograph of AMS 5749 after corrosion test.